

relatively vast as magnetic needles and rings of wire, whose inertia is very great as compared with that of spores, and the proportion of the surface exposed to the action of a surface viscosity is also much greater for a spore of dimensions only about 1μ than for a needle or wire.

There is at present no evidence of an electrical factor in the phenomenon, but further work on this point is in progress.

The Transmission of Cathode Rays through Matter.

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The experiments of this paper are the outcome of an attempt to discover whether cathode rays are selectively absorbed when their speed is sufficient to excite the radiation characteristic of the material they traverse.

The general laws of absorption of cathode rays were elucidated many years ago by Lenard,* and the law which bears his name is expressed by the relation

$$I = I_0 e^{-\lambda x},$$

where I_0 is the "intensity" of a beam of cathode rays incident on an absorbing sheet of thickness x , and I is the "intensity" of the emergent rays. The intensity, as measured by Lenard, was indicated by the brightness of a phosphorescent screen struck by the rays. In the above formula λ is the absorption coefficient. For a definite initial speed of ray λ/ρ is constant, ρ being the density of the absorbing material, while for any material Lenard found that λ varied inversely as the fourth power of the speed of the rays.

In the present experiments the number of the cathode rays incident on and emergent from various metallic sheets is studied.

The general disposition of apparatus is shown in fig. 1, which is not drawn to scale (ebonite insulation is shaded in the diagram).

T is a narrow brass tube passing through an ebonite plug tightly fitting the small brass cylinder C. The top of C consists of the metal leaf under examination, the leaf and the material of C being in close contact. D is another brass cylinder of slightly larger diameter insulated from C by an

* Lenard, 'Wied. Ann.,' vol. 56, p. 255 (1895).

ebonite ring. The cylinders C and D were provided with side tubes connected with rubber tubing, so as to prevent the existence of any pressure difference tending to rupture the leaf.

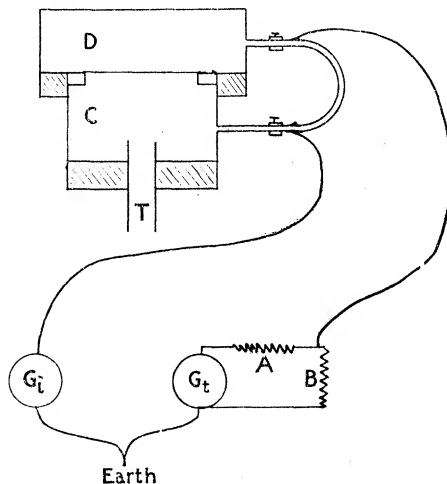


FIG. 1.

Homogeneous cathode rays of known velocity produced by means of a discharge tube and solenoid cylinder* were fired down the tube T.

The rays transmitted by the leaf were measured by the current flowing to earth through the galvanometer G_t , all the transmitted rays being caught by the cylinder D. The rays reflected from and stopped by the leaf were in like manner measured by the galvanometer G_i . These galvanometers were of the moving coil type, the spots of light reflected from their mirrors being focussed on the same scale. It was found that the instrument represented by G_i had to be capable of measuring currents varying between very wide limits, since with slow rays incident on the leaf only a very small number are transmitted, while with fast rays a far greater number are able to penetrate.

For this reason a very sensitive galvanometer was used in conjunction with a shunt of the "Universal" type, indicated by the resistances A and B in the diagram. With this arrangement currents down to 10^{-10} ampère could be conveniently measured.

For the purposes of these experiments only the relative values of the currents i and t registered by the galvanometers G_i and G_t are required. Preliminary experiments were therefore carried out in order to determine the factors, denoted by k in the following equation, by which the actual readings of G_t (with various values of A and B) were to be multiplied to reduce them

* For details of this apparatus see 'Roy. Soc. Proc.,' A, vol. 85, p. 324 (1911).

to the readings which G_i , unshunted, would have yielded with the same current. This was simply done by connecting up both galvanometers in series, passing the same current through both and comparing the readings of the two instruments with various values of A and B.

It was found that k was a function of A and B alone and was independent of the rate of the coil break.

If i and t are the readings of the galvanometers corresponding to the incident and transmitted currents, then of the total current incident on the leaf kt is transmitted. Thus, if the exponential law of absorption is obeyed we must have

$$\frac{kt}{i+kt} = e^{-\lambda x}.$$

The apparatus of fig. 1 is by no means suited to test this law, since it is necessary to take the apparatus down in order to change the thickness of the absorbing leaf. A few preliminary experiments, however, were performed with different thicknesses of absorbing material and cathode rays of a definite speed, and it appeared as if the law were at any rate approximately obeyed. As an example of many experiments to test this point we may take the case of the transmission of cathode rays of velocity about 6×10^9 cm./sec. through two and three sheets of aluminium. In the first case, $\log_{10} [(i+kt)/kt]$ came out 0.918, while in the second case it was 1.568. If the exponential law be obeyed, then the ratio of these logarithms should be the same as the ratio of the leaf thicknesses.

The logarithm ratio is 1.38, while the thickness ratio is 1.5. We may assume, therefore, that the exponential law is roughly obeyed.

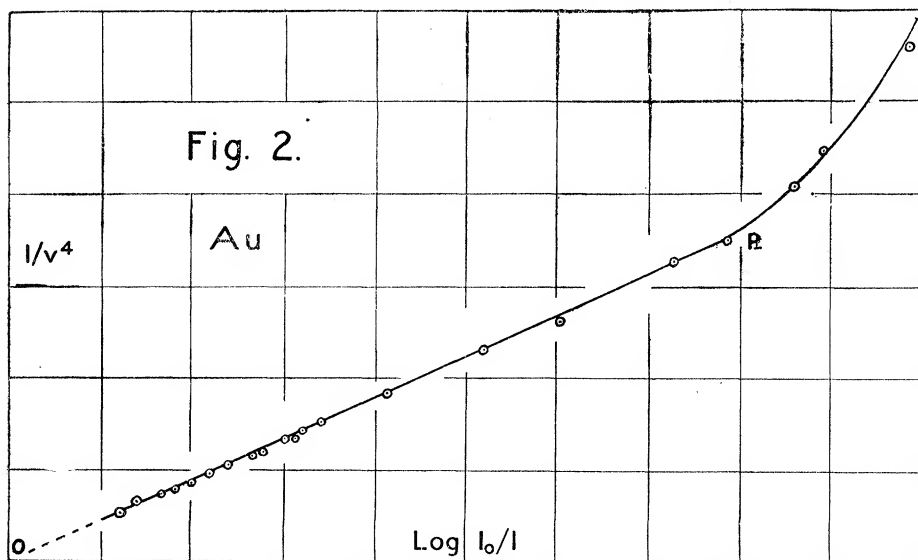
Turning now to the main object of the experiments. Measurements of i and t were made with great care, using a definite known thickness of leaf and varying the cathode ray speed over the widest possible limits.

The simplest results were obtained in the case of gold, the results for which are shown graphically in fig. 2.

In this curve the ordinates are proportional to $1/v^4$, while the corresponding abscissæ are proportional to λ , or, what is the same thing, to $\log_{10} [(i+kt)/kt]$. It is clear from this curve that over a considerable range of velocities, λ is proportional to $1/v^4$, or that λv^4 is constant.

Departure from this relation, however, evidently takes place at the point P. Experiment shows that the position of this point depends on the thickness of the absorbing sheet, thicker leaves involving a shift of P down the curve towards the origin. Now, it has been shown in a previous paper* that the

* Whiddington, 'Roy. Soc. Proc.,' A, vol. 86, p. 365 (1912).



loss of velocity of cathode rays in passing through an absorbing material is expressed with considerable accuracy by the relation

$$v_0^4 - v_x^4 = ax,$$

where v_0 = the speed of the rays incident on a sheet of thickness x ,
 v_x = the speed of the fastest transmitted rays,
 a = a constant depending on the material of the sheet.

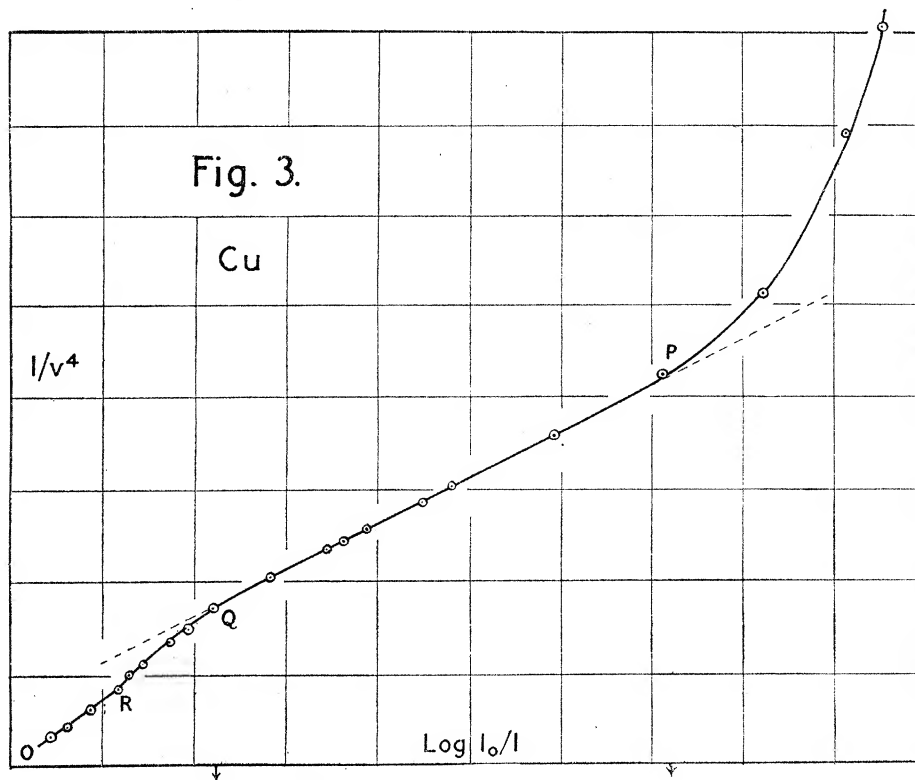
If in the above formula v_x is put equal to zero, then x will be that thickness of material which can just be traversed by rays of initial speed v_0 , or, put in another way, x is the range in the material of cathode rays of speed v_0 , the connection between the range and the speed being $v^4 = ax$.

This furnishes an immediate explanation of the point P in fig. 2. The value of the velocity v corresponding to P is connected with the thickness x of the leaf by the above relation, and it is thus possible to deduce from the position of P the value of the constant a .

This constant, calculated from the position of P for very different leaf thicknesses, shows little variation and agrees quite well with the results given in the paper already referred to. A table of results showing the values of a for different materials is given later.

Fig. 3 shows the shape of the $\lambda, 1/v^4$ curve in the case of copper. In this case there is also a linear part in the curve, limited however at both the high- and the low-velocity ends. At the low-velocity end the point P occurs as in the case of gold, and at the high-velocity end there is, in addition,

a point of inflection Q. The position of this point does not appear to depend on the thickness of the absorbing leaf, unless, of course, the thickness is so great as to make P approach too near it. After the point R has been passed, the curve again tends to become straight, and, if produced, passes at any rate very nearly through the origin. Thus it is apparent that over the greater part of this curve, over the range of velocities included between the points P and Q, λv^4 is *not* constant.



It is of interest to notice that the point P corresponds to a velocity of 6.2×10^9 cm./sec., which is almost exactly the speed of cathode ray required to excite the radiation characteristic of copper. The copper type of curve is exhibited by every other metal examined in detail, viz., aluminium, silver, and platinum. Gold stands alone in furnishing a simple straight line passing through the origin. The kink in the curves for the metals other than gold cannot be definitely ascribed to the excitation of the characteristic radiation of the element, since aluminium and platinum both show very well marked kinks in positions which have no very certain connection with the excitation velocity. Considerable trouble was experienced with tin as an

absorber. Very irregular results were obtained, it being found quite impossible to repeat observations to any degree of accuracy. It was ultimately noticed that the portion of leaf struck by the rays became extremely thin under the action of the rays, being apparently volatilised; in fact, bombardment by cathode rays in the case of tin would appear to be a convenient method of preparing thin films of this metal.

The equation to the linear part of the curve of figs. 2 and 3 is

$$\lambda = \frac{b}{v^4} + c.$$

The following Table I gives the values of b and c for the metals examined. From this table the value of λ for any speed less than that corresponding to the point Q (v_Q) can be calculated. The last column gives the thickness of leaf experimented with.

Table I.

Absorber.	b .	c .	v_Q .	Leaf thickness in cm.
Al	$4 \cdot 70 \times 10^{43}$	— 20,000	$6 \cdot 47 \times 10^9$	$10 \cdot 4 \times 10^{-5}$
Cu	$7 \cdot 69 \times 10^{43}$	— 27,200	$6 \cdot 2 \times 10^9$	$2 \cdot 23 \times 10^{-5}$
Ag	$11 \cdot 42 \times 10^{43}$	— 5,900	$> 9 \cdot 0 \times 10^9$ *	$1 \cdot 92 \times 10^{-5}$
Au	$14 \cdot 28 \times 10^{43}$	0	$> 9 \cdot 0 \times 10^9$	$3 \cdot 25 \times 10^{-5}$
Pt	$19 \cdot 29 \times 10^{43}$	— 4,300	$5 \cdot 83 \times 10^9$	$2 \cdot 64 \times 10^{-5}$

* There is some uncertainty about the value of v_Q for Ag.

Table II gives the values of the constant a calculated from the position of the point P. The last column gives $a/\rho^{\frac{1}{2}}$, which is clearly nearly constant.

Table II.

Absorber.	a .	ρ .	$a/\rho^{\frac{1}{2}}$.
Al	$7 \cdot 3 \times 10^{42}$	2.7	$4 \cdot 38 \times 10^{42}$
Sn	$14 \cdot 9 \times 10^{42}$	7.4	$5 \cdot 49 \times 10^{42}$
Cu	$15 \cdot 3 \times 10^{42}$	8.9	$5 \cdot 4 \times 10^{42}$
Ag	$16 \cdot 9 \times 10^{42}$	10.5	$5 \cdot 2 \times 10^{42}$
Au	$25 \cdot 4 \times 10^{42}$	19.3	$5 \cdot 7 \times 10^{42}$
Pt	$28 \cdot 9 \times 10^{42}$	21.5	$6 \cdot 2 \times 10^{42}$

The relation expressing the change of speed suffered by α -rays in their passage through matter is

$$v_0^3 - v_x^3 = ax,$$

where the symbols have the same significance as in the similar formula for the cathode rays. Now a in this case is proportional to the stopping power

of the material for the rays. It follows from this that $a'/A^{\frac{1}{2}}$ is constant,* where A is the atomic weight of the absorbing material. I hope in a future paper to discuss these results and their bearing on some experiments which have been carried out on the absorption of cathode rays in gases.

Summary.

The experiments shortly described in this paper indicate that the law of Lenard stating that the absorption coefficient of cathode rays passing through thin metal sheets is connected with their speed by the relation $\lambda v^4 = \text{constant}$ is not generally true when λ is determined from the number of rays incident and transmitted. The alternative formula

$$\lambda = \frac{b}{v^4} + c$$

is shown to represent the facts closely within certain limits of velocity.

It appears that the lower limit of velocity is dependent only on the thickness of the absorbing sheet, while the upper limit is determined by the nature of the metal.

This upper limit in the case of copper screens corresponds exactly to the speed of ray required to excite the Röntgen radiation (K series) characteristic of copper (Curve 3). This is probably a coincidence, as the upper limit in the cases of other metals does not correspond to the excitation of a characteristic radiation. For gold screens the upper limit was not reached, so that for this metal the constant c is zero and therefore Lenard's law is obeyed over a considerable range.

The lower limit of speed provides a ready means of determining the constant a in the relation

$$v_0^4 - v_x^4 = ax,$$

determining the variation in speed of the rays traversing the absorbing sheet. Table II shows the approximate constancy of the ratio $a/\rho^{\frac{1}{2}}$, where ρ is the density of the absorber. In the parallel case of the α -rays the ratio $a'/A^{\frac{1}{2}}$ is constant where A is the atomic weight of the absorber, and $a' = aA/\rho$.

I have pleasure in thanking Prof. Sir J. J. Thomson for his interest in these experiments.

* $a' = aA/\rho$, a being proportional to the "stopping power" and a' to the "atomic stopping power."